SOIL CONSERVATION SERVICE

Constructed Wetlands for Agricultural Wastewater Treatment

Technical Requirements

August 9, 1991

A. INTRODUCTION

This document provides the Soil Conservation Service (SCS) technical requirements for constructed wetlands for agricultural wastewater treatment installed under the Agricultural Stabilization and Conservation Service (ASCS) program -- "Constructed Wetland Systems for Agricultural Waste Water Treatment, (WP6)." Refer to Notice ACP-257. Wastewater to be treated by constructed wetlands under these requirements includes that originating from livestock or aquaculture facilities.

These requirements are based primarily on studies of municipal waste treatment systems. Initial reports from agencies, such as the Environmental Protection Agency (EPA) and Tennessee Valley Authority (TVA) and from universities conducting work on constructed wetlands used for animal waste treatment suggests a high level of treatment when the constructed wetland follows treatment in a waste treatment lagoon. However, data is very limited. It is anticipated that as experience is gained in the use of constructed wetlands for animal waste treatment, these requirements will change and become more refined.

As is the case for all other waste management practices, a constructed wetland is to be employed as a component of an overall agricultural waste management system (AWMS). The AWMS is to be an integral part of the Resource Management System in which it operates. This is reinforced by the ASCS WP6 practice, which includes 21 SCS technical practice codes in addition to the constructed wetland technical requirement (Code 999).

Constructed wetlands applicable under these technical requirements are constructed aquatic ecosystems with rooted emergent hydrophytes designed and managed to treat agricultural wastewater. Constructed wetlands consist of adequate seepage control, a suitable plant medium (bed) for rooted emergent hydrophytic vegetation, the vegetation itself, wastewater flowing at a slow velocity through the system, and the structural components needed to contain and control the flow (See Figure 1).

Constructed wetlands treat wastewater in several ways, including settling, biochemical conversion, volatilization, evapotranspiration, and nutrient uptake. Within the water column, the stems of the plants serve as substrate for bacteria and other microorganisms important in the treatment process; this is perhaps the most important treatment mechanism in the constructed wetland. It is known that wetland plants translocate oxygen from the upper plant tissue to the roots. It is thought that oxygen diffuses through the root hairs to form a thin oxygen-rich zone where aerobic decomposition can occur; however, this mechanism for treatment is not fully understood and may be incidental to other mechanisms.

Agricultural wastewater addressed in this document is associated with confined livestock and aquaculture facilities. Applicable agricultural wastewater includes milkhouse wastewater, waste treatment lagoon effluent, agriculture pond effluent, and wastewater pretreated with settling basins or solid separation devices. Direct runoff from feedlots and barnyards into constructed wetlands is not to be allowed under these requirements because an intermittent supply of water would not support wetland systems. Cropland runoff constructed wetland Systems are not to be installed under this requirement.

Discharge (effluent) from constructed wetlands planned, designed, and constructed under the requirements of this document will be stored in a wastewater storage facility. The stored wastewater may be land applied or recycled through the AWMS. Effluent that has been treated in a constructed wetland may be discharged to receiving water if allowed by Federal, state, and local laws and if required permits for this discharge have been obtained.

Alternative agricultural waste management systems should be carefully considered in determining if a constructed wetland is an appropriate component of a system which will be resource efficient, resource conserving, economically feasible, socially supportive, and environmentally sound. The Agricultural Waste Management Field Handbook should be referenced in making these considerations as it gives details needed in planning agricultural waste management systems. It will also be found helpful in the design of constructed wetlands.

B. SUMMARY OF TECHNICAL REQUIREMENTS

The following is a summary of the requirement for planning, design, construction, operation and maintenance, and monitoring of constructed wetlands. These requirement are explained in greater detail in the appropriate sections of this document.

- Constructed wetlands will be a component of a planned AWMS.

- Wastewater to be treated by constructed wetlands will originate from livestock or aquaculture facilities.

- Constructed wetland wastewater to be treated will not include direct runoff from confined animal feedlots and barnyards. Runoff from cropland, or other agricultural land, either direct or from storage, is expressly excluded from the purview of these requirements.

- Wastewater will be pretreated to reduce the concentration of nutrients and solids before it is introduced into constructed wetlands. Dilution to reduce the strength of the wastewater will be necessary for most systems.

- Wastewater will be of sufficient volume and duration to keep the constructed wetland moist at all times.

- Constructed wetlands will be planned, designed, constructed, operated and maintained in accordance with all Federal, State, and local laws and regulations.

- Constructed wetlands will be sited outside the limits of jurisdictional wetlands of any classification.

- Operation and maintenance plans developed for constructed wetlands will include at least the minimum level of monitoring (see Section F).

- Constructed wetlands will be designed as a surface flow type (subsurface flow type systems will not be permitted until research demonstrates their long term effectiveness).

- Constructed wetlands will discharge to storage facilities to allow for land application in an environmentally sound manner or recycled through the agricultural waste management system unless Federal, State and local regulation allow otherwise.

- The constructed wetland will be designed to discourage use by wildlife which may be negatively impacted.

- To the extent possible, constructed wetlands are to be sited and designed to fit the topography, vegetation and other land use patterns, and are to be an integral part of the ecosystem.

C. PLANNING REQUIREMENTS

Constructed wetlands have the potential to treat wastewater from sources outlined in the introduction. However, this treatment cannot be accomplished without proper planning. The following considerations need to be addressed in the initial planning process:

1. Relationship to other components of AWMS. A primary consideration in planning is the relationship of the constructed wetland to other components of the planned AWMS.

2. Federal, State, and Local Regulations. Any constructed wetland which could discharge effluent across property lines or into receiving water must first be approved by the State Water Quality Agency and satisfy any local regulations governing discharges of wastewater.

3. Site Evaluation.

   Onsite evaluation of potential sites for constructed wetlands should include:

a. Physical dimensions of the site.

b. Topography.

c. Current and future land use.

d. Surface and ground water conditions.

   1. Flooding and drainage problems.

   2. Location and depth of aquifers.

e. Soil characteristics

   1. Soil survey maps and associated information.

   2. Soil borings for sampling and logging.

   3. Physical and chemical properties.

f. Type of farm operation such as dairy, swine, poultry, beef, or aquaculture.

g. Hydrologic activity of the site such as runoff management needs, volume of runoff, and peak flows.

h. Cultural resources.

i. Existing vegetation such as hydrophytic vegetation near the site.

j. Location and extent of existing wetlands.

k. Location, extent, and classification of receiving waters such as streams, lakes, and groundwater.

l. Sociological resources such as locations and distance to homes.

m. Depth to bedrock.

4. Feasibility.

In determining the feasibility of implementing this practice, an evaluation of the site, including appropriate soil survey data and information, should be completed. Additionally, consideration should be given to the potential impacts to the environment and to the decisionmaker’s economic needs and conditions. This will include determination of the decisionmakers's short and long-term objectives and his/her willingness and ability to manage the constructed wetland. These determinations will be made in the context of the entire farm/ranch operation and the local community.

5. Flexibility.

Flexibility should be integral to design and monitoring in order to accommodate changing needs and conditions. Consideration should be given to potential for growth and expansion of the operation. Constructed wetlands and other AWMS components should be located to provide adequate wastewater treatment as a result of expansion of the operation.

6. Pretreatment Requirements

Wastewater from confined feeding operations will require treatment to reduce solids, organic material, nitrogen, and phosphorus to acceptable levels before they are discharged to constructed wetlands. Pretreatment must remove most settleable, floating, and nondegradable materials. It must also reduce nutrient and organic loads to ensure survivability of the vegetation. Pretreatment can be accomplished using lagoons, dilution, settling basins and mechanical separator either singly or in combination. Dilution of the wastewater before it enters the constructed wetland will be necessary for most systems.

7. Location of System.

Constructed wetland locations are to be based on soils and geologic data and other physical factors. They will be located as near the source of wastewater as practical and downgrade if at all possible. The site must be protected from flooding, erosion, sedimentation, high ground water tables, and leaching. Unpolluted runoff from outside drainage areas should not enter the constructed wetland unless designed into the system to dilute wastewater or to sustain vegetation during dry periods. Constructed wetlands should be located away from neighboring dwellings if odors or mosquitoes and other insects could be a problem. The site should be accessible for construction and for ongoing operation and maintenance after construction. Public access to the site should be controlled.

8. Types of Constructed Wetlands.

There are two basic designs for constructed wetlands: surface flow constructed wetland and subsurface flow constructed wetland. These technical requirements apply only to surface flow constructed wetlands. Surface flow constructed wetlands (see Figure 1) consist of water flowing across the bed within a basin or channel and having a free-water surface (also called a free-watersurface constructed wetland). A subsurface flow constructed wetland consists of water flowing through a permeable medium placed on the bottom of the constructed wetland and overlying a less permeable soil or liner (also called a vegetated submerged bed constructed wetland). The bed for the subsurface flow wetland serves as a medium for microbial growth. With time, microbe colonization and solid material in the wastewater may clog the bed. An adequate method to backflush the bed of a subsurface flow constructed wetland is not available. For this reason, the subsurface type constructed wetland is not to be used to treat agricultural wastewater under these technical requirements and will not be discussed further in this document.

9. Site Size.

Sufficient area is needed to install one or more treatment cells according to the loading criteria (see Design) while allowing ample room for dikes, berms, diversion, operation, and maintenance as needed. Every effort should be made to plan and design constructed wetlands so that they will be an integral part of the ecosystem. Planning and design for example, should consider the relationship of constructed wetlands to nearby water fowl and upland bird habitat, and relationship to downstream riparian corridors -- water temperature, fisheries, etc.

10. Vegetation.

Vegetation selected for the constructed wetland will be emergent hydrophytic plants suitable for local climatic conditions and tolerant of the concentrations of nitrogen and other constituents in the wastewater. Principal plants to be used include cattail, maidencane, bulrush, rushes, and reeds. Plants that are unproven for wastewater treatment will not be used without approval of the State Resource Conservationist.

Although natural wetlands typically have a wide diversity of plant life, attempts to reproduce the natural diversity in a constructed wetland have proven unnecessary. Cattails alone or in combination with either reeds or bulrushes will often dominate in an established system. If the constructed wetland is divided into cells, there is opportunity for diversity by planting cells differently with single species selected from the list of principal constructed wetland plants presented in the design section of these requirements.

Free floating plants, such as water hyacinth and duckweed, have proven useful in municipal treatment systems; however, they are not to be used in constructed wetlands associated with these requirements due to the need for harvesting. For aesthetics and beautification, consider blueflag iris, canna lily, ginger lily,-and wildflowers on dikes and other disturbed areas. See design section for a list of plants that can be used in constructed wetlands.

Nutrient uptake is not a major consideration in plant selection. The roots and stems in the water column serve as a medium for bacterial growth and serve as a media for filtration and adsorption of solids, enhancing settling, filtration and adsorption. The stems and leaves at or above the water surface provide shade and thus reduce growth of algae. Wetland plants provide for the transfer of oxygen to and from the submerged parts of the constructed wetland plants.

11. Water Requirements.

Planning must consider the following water requirement to operate constructed wetlands:

a. Clean water that is required for the startup phase in operation of constructed wetlands.

b. Clean water that might be required to dilute the wastewater from livestock confinement facilities so it will have sufficient volume and duration to keep the constructed wetland bed wet. The constructed wetland bed must be kept wet at all times.

c. Clean water that might be required to reduce the concentration of nitrogen and other constituents which could damage plants if initially applied at high concentrations.

12. Effluent Control.

The waste management plan for the overall system should address the management, utilization, disposal, or discharge of effluent from the constructed wetland. Federal, state, and local laws and regulations must be satisfied if effluent is to be discharged to receiving surface water.

13. Wastewater Conveyance

Consideration must be given to the clogging of pipelines, gates, valves and other water conveyance devices. Struvite, bacterial slime, and floating debris are examples of the types of material that can clog water control and conveyance devices. Using floating inlets, orifice outlets, and other similar measures can minimize clogging problems.

14. Seasonal Effects.

Constructed wetlands will have reduced effectiveness during cold periods of the year due to lower water temperatures. Some climates may require that loading of constructed wetlands end when vegetation dormancy begins, while other climates may require only that loading be reduced as temperatures drop, and gradually increase as temperatures rise in the spring. Otherwise, systems will have to be proportioned for the reduced reaction rates

that occur during the winter months. Storage of wastewater may be necessary to allow for the reduced loading rates during the dormancy period.

15. Pest and Vector Control.

The population of mosquitoes and other vectors are to be controlled to prevent the potential for disease transmission and nuisance. Vectors can possibly be controlled by design and management. If mosquitoes become a problem, the population can be reduced by draining the wetland for about a week to help break the breeding cycle. This might need to be done on a regular basis for adequate control. This approach will be workable where the wetland is constructed in a series of parallel cells allowing for some cells to remain in operation while others are drained. For dilute wastes, mosquito fish (Gambusia), which eat mosquito larvae, can be introduced to the constructed wetland where permitted by state law.

Burrowing rodents such as muskrats can be harmful to the system. These animals could burrow through embankments at the water level and cause short-circuiting of the wastewater between constructed wetland cells. Rodents may be controlled through design and management or by population control.

16. Wildlife Considerations.

Constructed wetlands may attract wildlife, such as birds, amphibians, reptiles, and mammals. Some wildlife could be adversely affected by the accumulation and concentration of harmful or toxic pollutants. For this reason, care should be exercised when handling any wildlife harvested from such areas to prevent the transmission of disease to humans or other animals. Consideration should be given to measures to exclude, minimize attractiveness, or attract wildlife away from the constructed wetland.

17. Water Sampling and Testing

Existing wastewater management facilities must be sampled and tested to determine pollutant concentrations that will be entering the constructed wetland. Parameters needed for design are ammonia (NH_3+NH_4-N), total Kjeldahl nitrogen (TKN), total phosphorus {TP), five-day biochemical oxygen demand (BOD_5), and total solids (TS). Other parameters may be required depending on the type of operation. Automatic flow measuring devices to measure constructed wetland inflow and outflow should be considered.

18. Constructed Wetland Loading Rates

Consideration must be given to the type of wetland plants to be used when determining loading rates for constructed wetlands. Certain hydrophytic vegetation species are less tolerant to ammonia loads than others. Cattails can tolerate ammonia in ranges from 30 to 80 mg/L. Other known tolerance levels for species such as maidencane, pickerelweed, and arrowhead range in concentrations from 2 to 40 mg/L. Typha indicates good tolerance to ammonia. These species and others may tolerate higher ammonia concentrations as they become acclimated to the constructed wetland.

19. Water Rights.

Riparian water laws, primarily in states east of the Mississippi River, protect the rights of landowners along a watercourse for use of the water. The appropriation laws in the Western states protect the rights of priority users of the water. In addition to surface water in well-defined channels or basins, many states also regulate or control other superficial water and ground water. State and local discharge requirements for the appropriate situation should be determined prior to initiation of design.

20. Recycling and Recirculation Potential.

Recycling treated effluent back through the AWMS as process water can dilute influent BOD and suspended solids, decrease odor potential and possibly increase dissolved oxygen concentration and detention time, which will in turn could enhance nitrification. Oxygen content of recycled effluent could possibly be increased by applying it through a spray system or cascading it back into the cell, but this approach has not proven effective in increasing oxygen concentration of outflow (oxygen will likely be completely utilized near the upstream end).

Disadvantages to recirculation include increased construction costs and increased operation and maintenance.

21. Soil and Geology

Soil and geologic site information needed for planning the constructed wetland component of a waste management system can be obtained from section II of the Field Office Technical Guide, soil database, or published soil survey reports. Specific soil and geologic information based on site investigation will be required for design.

Soil data and geologic site information can be divided into two groups.

1. Soil and geologic properties of the site which affect design and construction requirements for constructed wetlands.

2. Soil and geologic properties which affect plant growth within constructed wetlands.

Detailed information on site~specific soil and geologic requirements for constructed wetlands is given in seepage control requirement and planting medium requirement subsections under the design section of this document. Since soil and geologic data required for design of constructed wetlands vary from region to region, additional data may be required by the State Conservation Engineer.

D. DESIGN REQUIREMENTS

1. Design Objectives

The design of constructed wetlands should be based on the treatment objectives, quality of the influent, and realistic performance expectations. Designs should consider the relationships between the constructed wetland and other resource systems.

The following will be the minimum treatment objectives based on effluent concentrations from the constructed wetland unless otherwise required or allowed by the appropriate regulatory agencies. If the effluent from the constructed wetland is stored and then land applied, the values noted below do not apply.

BOD_5 < 30 mg/L
TSS < 30 mg/L
NH_3+ NH_4 -N < 10 mg/L

Other more stringent criteria may be included in state requirements based on limitations associated with affected water bodies and research needs.

2. Pretreatment Requirements

The quality of the constructed wetland influent will be determined by the characteristics of the wastewater and the degree of pretreatment. It must be controlled to manage the characteristics of the constructed wetland effluent. Through pretreatment, removal of most settleable solids and materials that are not readily biodegradable, such as plastics and grease, will be enhanced. It will also reduce nutrient and organic loads which will help survivability of the constructed wetland vegetation. Dilution of the wastewater may be required to reduce the concentration of nitrogen and other constituents which could damage plants if applied at high concentrations. This will help ensure adequate quality of the constructed wetland effluent.

Target concentrations resulting from wastewater pretreatment for wastewater entering constructed wetlands should be approximately 1,500 mg/L total solids (TS), and 100 mg/L ammonia. See Section C, Planning Requirements, for cautions related to effect of ammonia on vegetation. Concentrations above these concentration levels for constructed wetland influent should be used with caution and justifiable reason for doing so. Alternatives for pretreatment include lagoons, settling basins, dilution, and mechanical separation used singly or in combination with other practices.

Estimated percent reductions in BOD_5 for single-cell anaerobic lagoons is 75 percent in warm climates and 60 percent in cool climates. Different values of percent reduction will have to be established for other lagoon configurations and storage periods. Local values are to be used where available.

3. Constructed Wetland Configuration

Once the overall surface area of the constructed wetland is determined (see paragraph 4 below), the constructed wetland should be shaped with an overall length to width ratio of 3:1 to 4:1. This overall layout should then be subdivided into parallel cells (side-by-side in the widthwise direction-see figure 2), each having a length to width ratio of about 10:1. Dikes will be used to create the division into the parallel cells. The purpose of this division into cells is to ensure uniform flow down the length of the system and, thereby, maintain maximum contact with all the vegetation. It will also facilitate operation and maintenance. Wastewater will be delivered across the width of all the individual cells simultaneously at the same flow rate, except when certain cells are drained for maintenance or mosquito control.

In the length wise direction, the individual parallel cells may need to be divided into a series; thus, each of the parallel cells will discharge into a downstream cell having the same width. This may be necessary to prevent the water in any one cell form being deeper than about 8 inches. For instance, if the bottom slope of a cell is 0.5 percent and the water depth at the upper end is 4 inches, the depth at the end of 100 foot cell would be 10 inches. If the required length for the overall system is 400 feet, the individual parallel cells will need to be divided lengthwise to reestablish the needed shallow flow depth. Consequently, a constructed wetland with overall dimensions of 400' x 100' (note: L:W = 4:1), could contain a battery of four 25' x 30' primary cells, followed by four batteries of four cells each, or 20 individual cells total. (Note that the length to width ratio of the individual cells in this case was not 10:1. The planner will need to evaluate the requirements of each site individually, taking into account construction costs and workability of each design.)

The top width of dikes used to surround and divide the constructed wetland must be wide enough to accommodate the requirements of construction, and operation and maintenance. The bottom slope must be essentially flat to facilitate uniform depth of water throughout the system as noted above.

4. Size Requirements

Two methods are presented which allow for sizing of constructed wetlands. The first, which is called the Presumptive Method, is based on guidelines presented by Dr. Donald Hammer, Project Manager in the Waste Technology Program of the Tennessee Valley Authority; the second method is based on an equation presented by Reed, et.al.

NEITHER OF THESE METHODS HAS BEEN THOROUGHLY EVALUATED FOR ANIMAL WASTE SYSTEMS OVER AN EXTENDED PERIOD OF TIME AND AT A VARIETY OF LOCATIONS. INITIAL DATA FOR THE PRESUMPTIVE METHOD APPEARS PROMISING. THESE METHODS ARE CONSIDERED STATE OF THE ART AND WILL LIKELY BE MODIFIED AND REFINED AS ADDITIONAL SYSTEMS ARE INSTALLED AND MONITORED AS PART OF THE DEMONSTRATIONS ASSOCIATED WITH THESE TECHNICAL REQUIREMENTS.

a. Presumptive Method

This method presumes a certain amount of BOD_5 is produced by the animals and a certain amount lost through the selected treatment method. It then uses these values with an accepted areal loading rate for the constructed wetland to determine surface area required for treatment.

The areal loading rate using this method will be 65 lb. BOD_5/ac/day. Although this loading rate may eventually be adjusted to reflect different levels of treatment based on climate, no research or field data are currently available to justify use of increased values.

The presumptive method is especially useful when a pretreatment system has not yet been installed and the concentration of BOD_5 in the pretreatment component must be estimated. The presumptive method determines the acres of water surface area required for treatment. Hydraulic residence time is then computed as noted below.

b. Field Test Method

The second method uses hydraulic residence time equations in which known (measured) concentrations of BOD_5 can be used. It includes allowance for water temperatures which allows adjustment for climate. The equation includes a reaction rate constant which may not be completely accurate for all locations and site conditions. In addition, the equation incorporates a factor which adjusts for porosity of the cells or volume not occupied by plants. Since plants will occupy from 2 to 14 percent of the water volume, some error is introduced if the plants used in the constructed wetland occupy a different volume than that reflected in the equation. Using this method, hydraulic residence time is first determined and then surface area.

5. Hydraulic residence time

Hydraulic residence time in the constructed wetland must be at least 12 days. It can be calculated for each of the two methods mentioned in 4 above.

a. Hydraulic resident time (t) for the presumptive method is calculated after the surface area (SA) is determined. Additional inputs needed to determine the residence time are daily flow rate (Q), average depth of water (D), and porosity (P)

$t = SA \times D \times P/Q$

where:

t = hydraulic residence time, days

SA = surface area of constructed wetland, ft^2

D = flow depth in constructed wetland, ft

Q = flow rate, ft^3/day

P = porosity is the ratio of the volume of the constructed wetland occupied by water to the volume of the constructed wetland occupied by plants and water. Watson and Hobson reported porosity values for selected constructed wetland plants as follows:

Cattails (<u>Tvpha</u>) = 0.95
Bulrush (Scirpus validus) = 0.86
Reeds (Phragmites) = 0.98
Rushes (Juncus) = 0.95

b. Hydraulic residence time for the field test method involves collecting samples from the lagoon or other pretreatment unit and using them in the following equation:

$t = 2.7 (\ln C_i - \ln C_e + \ln A) / 1.1^{(T-20)}$

or

$t = (\ln C_i - \ln C_e + \ln A) / 65K$

where:

t = hydraulic residence time, days

C_i = the constructed wetland influent BOD_5 concentration, mg/L the desired constructed wetland BOD_5 effluent concentration, mg/L

ln = natural logarithm

A = the fraction of BOD not removed as settleable solids near the head of the constructed wetland. (expressed as a decimal fraction, e.g., soluble BOD/total BOD)

T = water temperature, °C

KT = temperature dependent reaction rate constant, days

$= 0.0057(l.l)^{(T-20)}$

This equation for t is used when sizing the constructed wetland based on known concentrations of influent BOD_5.

The value used for (A) in municipal systems is about 0.52. This should be the lower limit for (A) unless research indicates otherwise. If organic material is adequately removed in pretreatment, the value may be increased, but is not to exceed 0.90 (for a waste treatment lagoon designed to SCS standards preceding the constructed wetland, the value of A may equal 0.90).

The values for (Ci) and (A) should be determined from an analysis of samples from the existing system if a pretreatment component is already in place such as a waste treatment lagoon. The sample should be representative of the lagoon supernatant (the liquid throughout the lagoon above the sludge layer). Several samples should be collected within the pretreatment unit and composited to represent the whole. Ideally, several representative samples should be collected during different seasons. Due to the variability of the BOD in these systems and to assure adequate safety, the value used for design should be the highest of the test results.

The temperature of the water (T) is controlled by local climatic conditions. The lowest water temperature under which the constructed wetland will be expected to perform should be used for design. In Northern states where the constructed wetland is expected to function during winter months, and when there is not complete freeze-up, the temperature of the water under the ice in a constructed wetland can be as high as 5°C. The wastewater may be stored in the pretreatment facilities during these cold season months in order to use a higher value for water temperature and thereby reducing the size requirement of the constructed wetland.

The hydraulic characteristics of the constructed wetland are designed to provide the required residence time (t). Hydraulic design of the constructed wetland is computed using the average depth of flow, and average daily flow rate into the system to find the arrangement that results in the required residence time.

6. Seepage Control Requirements

Constructed wetlands will provide adequate containment of wastewater within the system to prevent contamination of ground water. Requirements for seepage control depend on the hazard to the ground water determined by the State Conservation Engineer in cooperation with other Federal and state agencies.

Site specific soil and geologic data is required to determine the need for seepage control and if required, the type of seepage control needed. Data required - include the Unified classification, plasticity index, liquid limit, permeability, and bulk density of the soil; depth to bedrock; bedrock type; depth to water table, substrata permeability; and existence of karst or fractured bedrock.

The Unified classification, plasticity index, liquid limit, permeability, and bulk density are needed to evaluate the potential leaching of constructed wetland effluent and to determine the design, construction, and maintenance practices necessary to prevent effluent movement into the substrata below the constructed wetland. Depth to bedrock, bedrock type, and the degree of fracture impacts construction methods and equipment requirements.

Constructed wetlands should not be built over shallow water tables (water tables within 6 feet of the soil surface); karst or highly fractured bedrock; or substrata with moderate or higher permeability (greater than 0.2 inches per hour). If a constructed wetland under consideration is in an area where shallow water tables, karst or highly fractured bedrock, or high substrata permeability are unavoidable, then precaution described below must be taken to protect underlying ground water.

Compaction of in-situ soils to meet seepage reduction requirements should be investigated. Use of South National Technical Center (SNTC) Technical Note 716, "Design and Construction Guidelines for Considering Seepage from Agricultural Waste Storage Ponds and Treatment Lagoons" along with its companion SNTC Technical Note 717, "Measurement and Estimation of Permeability of Soils for Animal Waste Storage Facilities," provides needed guidance in determining when in-situ soils will adequately meet the seepage control needs. The services of the SCS engineering soil testing laboratories will also provide needed guidance. If insitu soils are not adequate, clay or synthetic liners are required. Clay liners will be designed and constructed in accordance with the above mentioned SNTC technical notes. Synthetic liners will be strong enough to prevent root penetration and be placed deep enough (>12") to allow maximum vertical root growth and in accordance with the manufacturer's recommendations.

7. Planting Medium Requirements

Soil properties that affect suitability as a planting medium are cation exchange capacity, pH, electrical conductivity, soil organic matter and soil textural class. Cation exchange capacity affects the exchange and retention of nutrients, heavy metals, and other potential pollutants. The cation exchange capacity of the soil used as a growth medium should be greater than 15 meq/100 grams of soil. The pH of the soil used as a growth medium affects the availability and retention of heavy metals and nutrients and should be between 6.5 and 8.5. Electrical conductivity (EC) of the growth medium affect the ability of the plants and microbes to process the waste material flowing into the constructed wetland. Soil with an EC less than 4 mmho/cm are best suited as growth medium for constructed wetlands. Soil texture affects root growth and retention of potential pollutants within the constructed wetland. Sandy soils will have a low retention of potential pollutants and little or no restriction on root growth. Conversely, clayey soils with clay content greater than 45% have high retention of potential pollutants, and restrict root growth. Medium textured or loamy soils are best suited plant medium for constructed wetlands as these soils have high retention of potential pollutants, and little restriction on root growth.

The planting medium should be placed on top of the layer prepared to prevent seepage. Equipment should be operated to avoid damage to seepage control layer or excessive compaction of the planting medium. After the plant medium has been spread and brought to grade, a light scarification or cultivation may be necessary to prepare the medium for planting.

The existing topsoil is typically removed prior to construction or installation of the liner. If the topsoil is acceptable, it can be stockpiled and then utilized as the planting medium (bed).

8. Plant Requirements

Plant materials selected for constructed wetlands will be emergent hydrophytic plants suitable for local climatic conditions and be tolerant of high concentrations of nitrogen and other pollutants in animal wastewater. The principal plants to use are:

cattail (Typha species)
bulrush (Scirpus species)
rushes (Juncus species)
reeds (Phragmites species)
maidencane (Panicum hemitomon)

Other species that may be suitable are:

canna lily (Canna flaccida)
water chestnut (Eleocharis dulcis)

pickerelweed (Pontederia cordata)
arrowhead (Sagittaria latifolia)
giant cutgrass (Zizaneonsis miliaceae)
elephant ear (Colocasia esculenta)
blueflag iris (Iris virginica)

For aesthetics and beautification of constructed wetland consider blueflag iris, canna lily, ginger lily, and include a wild flower mix in the vegetative plan for the dikes and other disturbed areas.

E. CONSTRUCTION REQUIREMENTS

1. SCS Responsibilities

Construction drawings, and construction and material specifications are to be complete and have the detail necessary to install the constructed wetland system. All lines and grades will be clearly noted on the drawings. Other construction requirements and details are to be clearly stated in the drawings and specifications. This includes the location of buried and overhead utilities within the construction limits. A pre-construction conference between the SCS inspector, the contractor, and the decisionmaker should be held at which time such items as construction details, construction sequence, location of plant materials, and borrow materials (if needed), construction survey, and final check-out and inspection items should be reviewed.

The construction inspection requirements should be determined and decisions made about the amount of layout and grade control assistance to be provided and equipment needed for construction inspection should be determined and approved by the State Conservation Engineer. Inspection of constructed wetland elements will be conducted at appropriate times during the construction sequence. Inspection should be conducted of the following elements:

- Clearing, grubbing and grading (minimize site disturbance)
- Seepage control layers, either existing soil materials, compacted in-situ soil materials or clay or synthetic liners
- Selection and placement of soils used for constructed wetland vegetation rooting medium
- Water level control and conveyance devices: materials, grades/elevations, and backfilling
- Placement and compaction of embankments

- Establishment of vegetation and, later, survival of vegetation

It is especially important to inspect the grades and elevations for water level control devices as they establish water levels crucial to operation of constructed wetlands.

2. Contractor Responsibilities

The contractor will be responsible for determining the sequence of installation of the constructed wetland elements. Site variables will dictate the sequence but generally the sequence is clearing and grubbing of excavation and borrow areas; excavation, transport, and stockpiling of soil to be used for embankment construction and/or planting medium for constructed wetland vegetation; excavation and recompaction of soil material used for the low permeability clay liner; installation of synthetic liners; backfilling and grading of soil used for constructed wetland vegetation planting medium; placement, shaping, and compaction of soil used for embankments; installation of water conveyances (pipes, weirs, flumes, etc.) including proper foundation preparation, backfilling, and soil piping prevention features; installation of erosion control features such as riprap and seeding of embankments and other disturbed areas; and planting of constructed wetland vegetation: and watering of site. Site preparation for and installation of water conveyance and level control devices can occur at different times in the construction sequence.

Installation and maintenance of devices and features to control erosion and prevent sediment transport off-site during construction is the contractor's responsibility. Local ordinances are to be followed for soil erosion and sediment control.

Equipment used for construction should be carefully selected because of the small areas in which it will work; critical grades that must be constructed; soil compaction that must be accomplished; excavation and transport of soil from borrow locations; and placement of soil materials in small amounts around structures installed in confined areas. Moisture control and compactive effort appropriate to the soil involved will be provided according to requirements stated in the drawings and specifications. Because of the importance of construction to exacting neat lines and grades, it may be advantageous to the contractor to use laser equipment to maintain grades and elevations.

The constructed elevation of the flow line will not vary more than 0.12 feet from the lines and grades shown on the construction drawings. Vegetation in areas that are 0.25 feet or more above the flow line, as constructed, will perform poorly or will not survive. The top of constructed embankments will be as high as the elevations shown on the drawings, never lower. Grades and elevations of water control devices will not vary more than 0.1 foot from elevations shown on the drawings.

3. Decisionmaker Responsibilities

The decisionmaker will be responsible for selecting a contractor and making contractual arrangements. In addition, the decisionmaker will be responsible for administering these arrangements and be ultimately responsible for all phases of the work.

Arrangements for protection or relocation of utilities will be made prior to construction and necessary actions taken to assure safety of people, farm animals, equipment and materials. The decisionmaker is responsible for contacting utility companies for needed actions that will be taken to protect or relocate utilities. Decisionmakers are also responsible for obtaining permits that might be required.

4. Plant Sources

Plant materials can be obtained from commercial sources and from local habitats. Plant materials obtained from commercial sources should be well adapted to local climatic conditions. Plant material should be healthy, vigorous and have a good root system. Cattail, bulrush, common reed, and maidencane collected should have the tops removed to 8 to 10 inches to prevent wind-throw before the roots have become established. The stalk should be long enough to extend above the water surface to prevent submergence and to better survive if the wastewater is low in dissolved oxygen.

5. Vegetation Establishment

Planting bulrush, cattail, maidencane, and other species should receive careful supervision because plants with damaged roots or plants that are planted incorrectly will not survive.

The plants can be planted with a dibble, trencher, or a one row tree planter. The planting depth will vary depending on species, in all cases the root system should be covered with soil to a depth of 4-6 inches. Plants should be established on about 3.0 ft. centers.

F. MONITORING REQUIREMENTS

1. General Requirements

A minimum level of monitoring (defined in 2. below) will be required for all constructed wetlands installed with ASCS cost-sharing assistance under their special trial program. The goal of monitoring is to evaluate the potential threat to surface and ground water quality so adjustments to-planning and design procedures can be made as necessary. The intensity of monitoring should be based on potential for a successful monitoring program, opportunities, and restrictions related to site variables, availability of equipment and personnel, and funding. Monitoring should account for the quantity of water accommodated by the system and assess the water quality parameters important to system function and environmental protection. It is important to determine reaction rates over a wide variety of conditions, learn how to optimize hydraulics and minimize short circuiting in cells, and to develop system life projections. Plant materials, operational features, system management, and fish and wildlife factors should also be considered for monitoring. In some sites leaching of potential pollutants to ground water should be evaluated.

Sample collection, management and testing are to be in accordance with established EPA procedures or Standard Methods for Examination of Water and Wastewater. Frequency of sampling and testing are to be commensurate with the established objectives.

Duration of the monitoring program will be a minimum of three years. Longer programs will be considered where long term contracts are involved.

Data gathered from all sites in a state will be managed in a single data base in each state. The format of the data base is to be coordinated with the NTC for the geographical area in which the state is located. Data evaluation will be the responsibility of each state with close coordination with their NTC.

The purposes and objectives for requiring monitoring of constructed wetlands under the ASCS program are to:

a. Characterize the quantity and quality of the inflow water to and the out flow from the constructed wetland basin in order to determine overall performance of the system. An assessment of the potential for discharge and a determination of the need for recycling by land application, recirculation for flushing, or other uses are key features of this item.

b. Define the physical, chemical, and biological processes active in the system in order to refine and develop design procedures and design parameters used to proportion systems needed to meet water quality goals.

c. Evaluate plant material species, and planting and management techniques.

2. Surface Water Parameters

The water quantity and quality parameters that need to be determined for constructed wetlands are in the following list. Those parameters marked (**) should be the minimum level of monitoring. Testing should be performed on samples taken at the inflow and outflow points and at points in between as needed to meet the established objectives. All units will be in mg/L unless otherwise noted.

- Flow in gpm and duration of flow, or flow at time of sampling **
- Total Kjeldahl Nitrogen {TKN) **
- Nitrate nitrogen (NO_3 - N)**
- Ammonia nitrogen (NH_3 + NH_4 - N)**

- Total Phosphorus (TP) **
- Total Suspended Solids (TSS)
- Total Dissolved Solids (TDS)**
- Fecal Coliform Bacteria (FC, #/100 mL)**
- Biochemical Oxygen Demand (BOD_5)
- Chemical Oxygen Demand (COD)
- Total Organic Carbon {TOC)
- Dissolved Oxygen (DO)**
- pH**
- Electrical Conductivity (MMHOS/cm)**
- Redox potential
- Temperature (T)**

3. Ground Water Parameters

Ground water monitoring should be accomplished through extraction of water samples from wells, lysimeters, or subsurface drains. Piezometers or other ground water level monitoring devices should be used to determine direction of ground water flow. Background levels of selected ground water constituents should be determined in order to assure that samples collected from around the constructed wetland are minimally influenced by water quality constituents from other sources.

The water quality parameters that should be investigated for ground water evaluations are listed below. Those marked (**) should be the minimum required:

- Nitrate nitrogen (NO_3 - N)**
- Fecal Coliform (FC, #100/mL)
- Chloride (C1) **
- Electrical conductivity (MMHOS/cm)
- Total Kjeldahl Nitrogen (TKN)
- Ammonia Nitrogen (NH_3 + NH_4 - N)

G. OPERATION AND MAINTENANCE REQUIREMENTS

1. Start-Up Phase

The start-up phase should begin immediately after a cell is planted. The purpose of the start-up phase is to establish the plants and ensure their survival, and then acclimate the plants to the wastewater. After a cell is planted, clean water should be added immediately to wet the soil and then the depth of water should be increased to a depth of 1 to 3 inches. This water level should be maintained until new growth appears on the plants. This period can last from two to four weeks. After good growth occurs and the plants begin to obtain a good height, the water level can be raised to design operating depth. At no time should water levels overtop plants. It is important to note that constructed wetlands are living ecosystems and their structure and function will be established before treatment or wastewater and pollutant removal will occur.

When the plants are well established at the design water depth, wastewater can be gradually loaded to the constructed wetland at a rate that will not shock the plants. Plant response to the wastewater must be observed during this period. Loading rate must be immediately reduced if plant damage is noted.

2. Water Flow and Depths

During the first winter, water levels should be raised to a depth that will prevent freeze damage of roots systems.

Routine weekly inspections are necessary to ensure equal flow from each outlet and inlet distributor piping. If clogging occurs, the obstruction must be removed. Plant debris obstructing outlet control structures must also be removed. Water levels in each cell should be checked and adjusted as necessary and all piping visually inspected for cracks or leaks. Dikes and flow control structures should be inspected for leaks and corrective action implemented.

Flow distribution within cells should be occasionally inspected to detect channel formation and short circuiting. Such problems should be corrected by planting vegetation or filling these channels with soil.

Pesticides or other chemicals that may harm the vegetation should not be directly applied or introduced into the wastewater stream. The water losses due to evapotranspiration can affect the operation and desired treatment levels during the hot summer months. Evaporative water losses in the summer months decrease the water volume in the system, and therefore the concentration of remaining pollutants tends to increase. Decreased water volume also increases the detention time and may increase the potential for anoxic or anaerobic conditions which will affect constructed wetland performance and could damage vegetation.

Where a waste treatment lagoon is the primary source of wastewater, water level in the lagoon could be lowered below the minimum operating elevation during dry periods. Alternative water sources should be made available to maintain optimum water in the animal waste treatment lagoon during these periods.

3. Vegetation

Vegetation should be visually inspected for signs of disease yellowing/browning, spots, wilting, etc.), insect infestations or stress (stunted growth) during other inspection periods.

Shrubs or trees are to be removed from constructed wetland cells and embankment areas because they might shade out desirable plant species and otherwise effect integrity of dikes and embankments. Dikes should be mowed at least annually to remove undesirable vegetation. Harvesting of constructed wetland plants is unnecessary as is the weeding of invading plants. Accumulated leaf and stalk litter create a desirable layer of humic materials in the cells within which much of the wastewater treatment occurs. Foot traffic should be minimized and vehicular traffic prevented within the cells because either will compress and damage the humic/compost surface layer.

Vegetative plants established on dikes, berms, and other disturbed areas will be in accordance with Practice Standard, Critical Area Planting, (Code 342).

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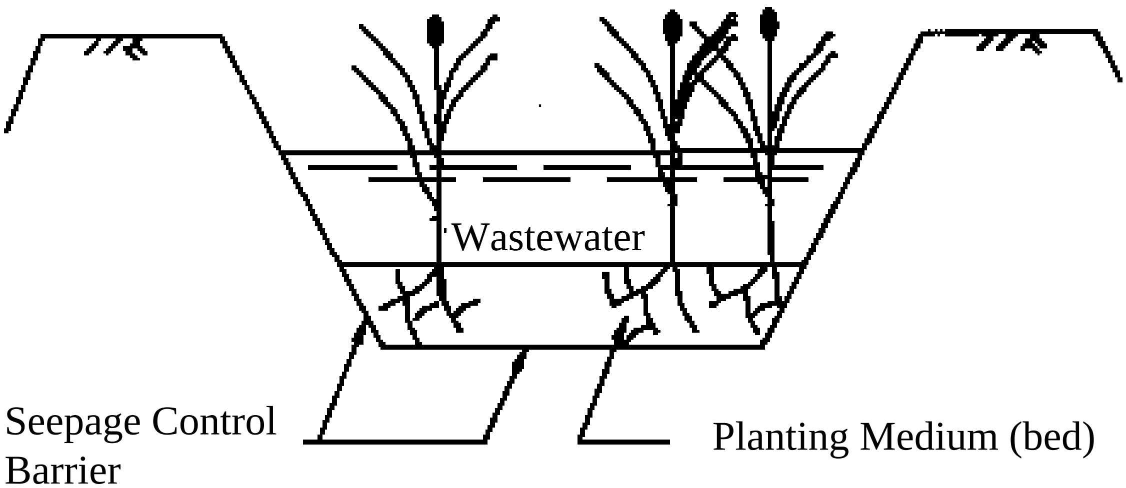
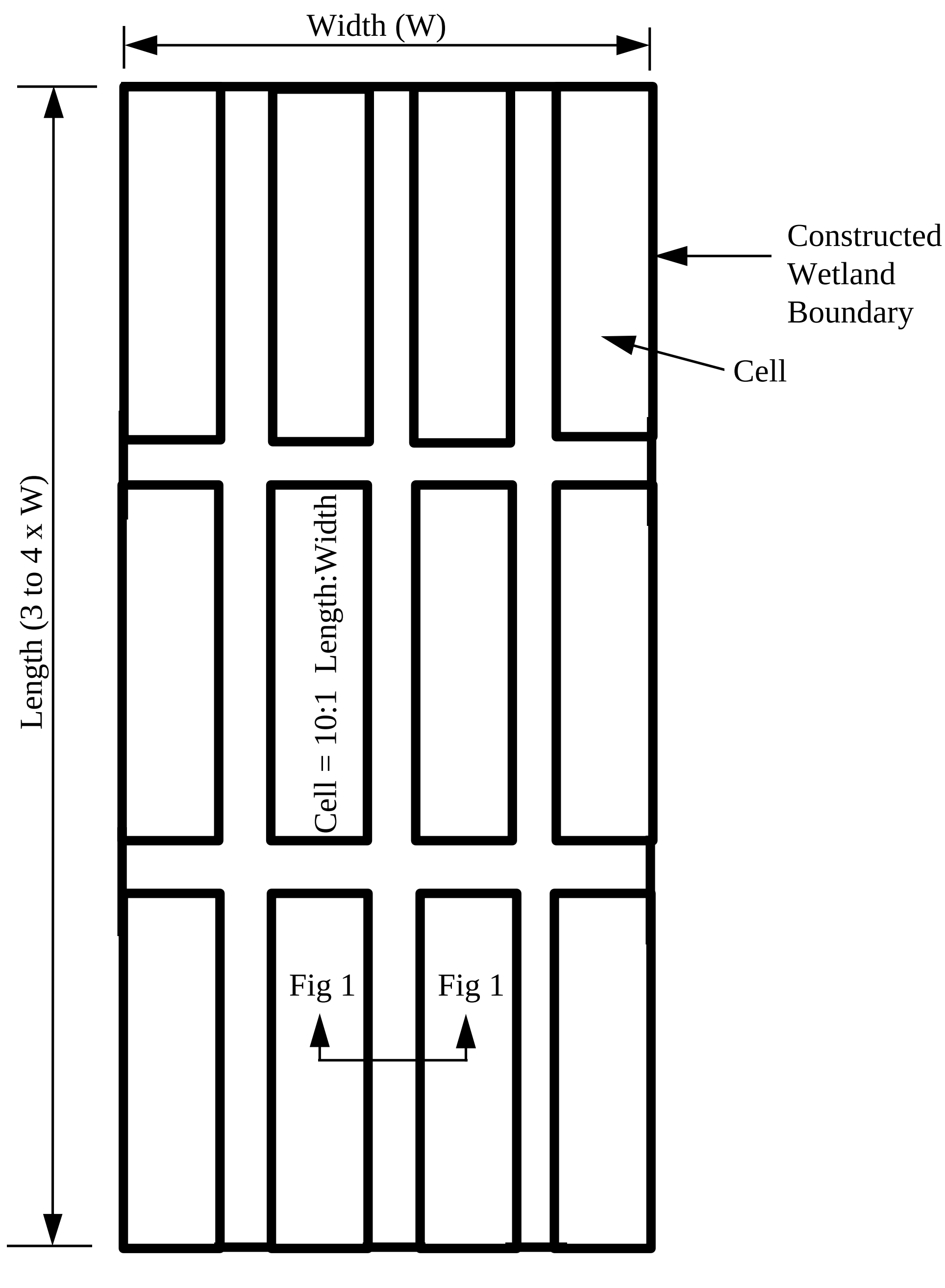
3. Watson, James T. and John A. Hobson. "Hydraulic Design Considerations and Control for Constructed Wetlands for Wastewater Treatment." in Constructed Wetlands for Wastewater Treatment -- Municipal, Industrial and Agricultural. ed. Donald A. Hammer. Lewis Publishers, Inc. (1989)

Technical Requirements for Constructed Wetlands for Agricultural Wastewater Treatment



Constructed Wetland Cell Cross Section
Figure 1

Technical Requirements
Constructed Wetlands for Agricultural Wastewater Treatment



Plan View
Constructed Wetland with Cells
Figure 2

Appendix

Design Examples

SIZING CONSTRUCTED WETLAND BASED ON AREAL BOD LOADING
(Presumptive method)

Given:

1. A dairy with 150 Jersey lactating cows with an average weight of 1000 lb. The dairy is located in South Carolina. Wastewater from the dairy will be pretreated with an anaerobic lagoon.

2. Allowable BOD_5 loading rate to the constructed wetland is 65 lb./ac/day.

3. Daily BOD_5 production in the animal waste (from the Agricultural Waste Management Field Handbook). 1.6 lb. BOD_5/1000 lb. AU/day

4. Average daily flow through the system is 780 cu ft/day, which includes flush water, rainfall minus evaporation on the lagoon, and wastewater displaced from the lagoon by the addition of animal waste solids.

5. Average depth of water in the constructed wetland is to be 8 inches.

6. Cattails (Typha) will be used as the principal wetland plant. This species will typically occupy 5 percent of the water volume in the constructed wetland (porosity = 95%).

Required:

Determine the surface area of the constructed wetland based on the presumptive method, and determine approximate overall dimensions assuming a length to width ratio of 4:1.

Solution:

Determine daily BOD_5 production

BOD_5 = BOD_5/1000# AU x No. of Animals x Average Weight/1000 x days

= (1.6) (150) (1000/1000) = 240 lb./day

Add 10% BOD_5 to account for amount in waste hay and feed. Therefore the daily BOD_5 loading to the lagoon is

BOD_5 = (240) (1.1) = 264 lb./day

Determine BOD_5 reduction by anaerobic lagoon pretreatment. Use rate of 75% reduction for warm climate (25% remaining).

Lagoon effluent (constructed wetland influent) would then contain:

BOD_5 = (264) (0.25) = 66 lb./day

Determine surface area for the constructed wetland

Allow BOD_5 loading rate of 65 lb./ac/day (see given)

Water surface area = BOD loading / BOD loading rate

= 66 / 65 = 1.0 acres = 43,560 sq. ft

Determine overall dimensions based on L:W = 4:1

Let W = width of CW
L = length = 4W

Then,

(4W) (W) = 43,560 sq. ft
W = 104 ft
L = 4W = 417 ft

One possible layout for this system could include a set of four cells in parallel providing initial treatment and a set of four additional cells in parallel which receive the waste from the upper set of cells.

The upper and lower groups of cells could each measure 25 ft by 210 ft. These dimensions are measured at the bottom of the cells where they intersect the embankment on either side and do not include consideration of dikes or embankments. The actual layout will be governed by the site configuration.

Determine hydraulic detention time:

t = surface area X depth X porosity / flow rate
t = 43,560 sq. ft X 0.67 ft X 0.95 / 780 cf/day
t = 36 days

SIZING CONSTRUCTED WETLAND BASED ON HYDRAULIC LOADING

Field Test Method

(with part-year discharge)

Given:

1. A dairy with 150 Jersey lactating cows with an average weight of 1000 lb.. Wastewater from the dairy will be pretreated with an anaerobic lagoon.
2. Daily flush water is 2000 gallons per day
3. Volume of manure production = 1.3 ft^3/1000 lb.
4. Annual precipitation is 52 inches
5. Annual evaporation is 44 inches
6. Maximum BOD_5 is 990 mg/L
7. Desired effluent BOD from constructed wetland is 30 mg/L
8. Average constructed wetland water temperature 14°C based on a March 1 to October 30 discharge from constructed wetland.
9. Lagoon dimensions are 150 feet by 200 feet.

Assumptions:

1. In this case, the lagoon functions as a facility for deposition of settleable BOD. Thus, A = 0.90
2. Lagoon is designed to not discharge from November 1 to February 28 when constructed wetland is not discharging.

Required: Constructed wetland size based on part-year hydraulic loading

Solution:

Determine detention time

$t = 2.7 (\ln C_i - \ln C_e + \ln A)/l.l^{(T\ 20)}$

Where C_i = 990 mg/L

$Ce = 30$ mg/L
$T = 14°C$
$A = 0.90$

$t = 2.7(1n\ 990 - \ln 30 + \ln 0.90)/ 1.1(14\text{-}2°)$

$= 2.7(6.9 - 3.4 - 0.12)/0.56$
$= 16.3$ days

Determine daily flow rate

Flush water volume = (gal/day) (days/yr.)/7.48 gal/ft^3

= (2000) (365)/7.48

= 97,S90 ft^3/year

Manure volume = ft3/1000# AU x No. of Animals x Average Weight/1000 x days

= (1.3) (150) (1000/1000) (365)

= 71,175 ft^3/year

Precipitation less evaporation as a volume

Volume = ((52 - 44)/12)) ((150)(200)) = 20,000 ft^3/year

Total Volume = Flush water + manure + precipitation less evaporation

= 97,590 + 71,175 + 20,000 - 188,765 ft^3/year

Daily flow rate = Total Volume/days of discharge

= 188,765/(8)(30) = 786 ft^3/day

Determine surface area required for constructed wetland

For a constructed wetland with a water depth of 8 inches, the surface area is:

Acs = ((Flow rate) (detention time)(depth/12))743,560

= ((786)(16.3)/(8/12))/43,560 = 0.37 <u>Use 0.44 acre</u>

SIZING CONSTRUCTED WETLAND BASED ON HYDRAULIC LOADING
(with year-round hydraulic loading)

Given:

1. A dairy with 150 Jersey lactating cows with an average weight of 1000 lb.. Wastewater from the dairy will be pretreated with an anaerobic lagoon.

2. Daily flush water is 2000 gallons per day

3. Volume of manure production = 1.3 ft^3/1000 lb. AU/day

4. Annual precipitation is 52 inches

5. Annual evaporation is 44 inches

6. Maximum BOD_5 is 990 mg/L

7. Desired effluent BOD from constructed wetland is 30 mg/L

8. Average constructed wetland water temperature 6°C based on a year-round discharge from constructed wetland.

9. Lagoon dimensions are 150 feet by 200 feet.

Assumptions:

1. A lagoon is used to settle BOD. Thus, A = 0.90

2. Lagoon is designed to discharge year-round.

Required: Constructed wetland size based on year-round hydraulic loading

Solution:

Determine detention time

$t = 2.7(1n\ C_i - \ln C_e + \ln A)/l.l^{(T\ 20)}$

Where C_i = 990 mg/L

C_e = 30 mg/L
T = 6°C
A = 0.90

$t = 2.7(1n\ 990 - \ln 30 + \ln 0.90)/ 1.1^{(6\text{-}20)}$
$= 2.7(6.9 - 3.4 - 0.12)/0.263$
$= 35$ days

Determine daily flow rate

Flush water volume = (gal/day) (days/yr.)/7.48 gal/ft^3

= (2000) (365)/7.48

= 97,590 ft^3/year

Manure volume = ft^3/1000# AU x No. of Animals x Average Weight/1000 x days

= (1.3) (150) (1000/1000)

= 71,175 ft^3/year

Precipitation less evaporation as a volume

Volume = ((52 - 44)/12)) ((150)(200)) = 20,000 ft^3/year

Total Volume = Flush water + manure + precipitation less evaporation

= 97,590 + 71,175 + 20,000 = 188,765 ft^3/year

Daily flow rate = Total Volume/days of discharge

= 188,765/365 = 517 ft^3/day

Determine surface area required for constructed wetland

For a constructed wetland with a water depth of 8 inches, the surface area is:

Acs = ((Flow rate) (detention time)(depth/12))/43,560

= ((517)(35)/(8/12))/43,560 = <u>0.62 acres</u>